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(54) **FLIGHT ALTITUDE ESTIMATION SYSTEMS AND METHODS**

(71) Applicant: **FLIR Unmanned Aerial Systems ULC**, Vancouver (CA)

(72) Inventors: **Michael Tribou**, Waterloo (CA); **Fei Yu**, Waterloo (CA); **Ian Melhuish**, Waterloo (CA); **Jerry Mailloux**, Wellesley (CA)

(73) Assignee: **FLIR Unmanned Aerial Systems ULC**, Vancouver (CA)

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H04B 7/185 (2006.01)

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CPC ***G08G 5/0069*** (2013.01); ***G08G 5/0017*** (2013.01); ***H04B 7/18504*** (2013.01)

(58) **Field of Classification Search**
CPC . G08G 5/0069; G08G 5/0017; H04B 7/18504
(Continued)

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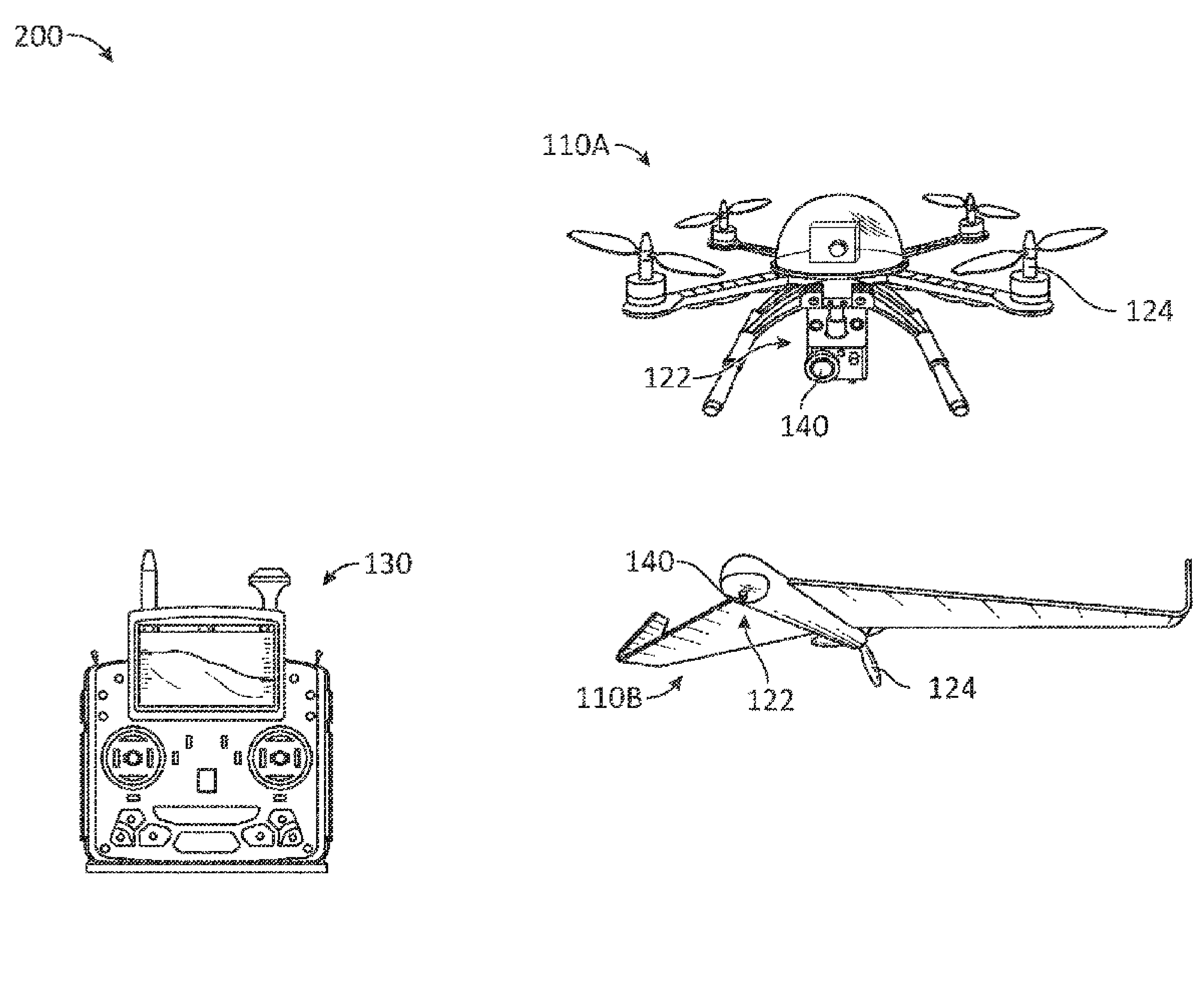
Primary Examiner — Kerri L McNally
(74) *Attorney, Agent, or Firm* — Haynes and Boone, LLP

(57) **ABSTRACT**

Unmanned aircraft systems (UASs) and related techniques are provided to improve the operation of unmanned mobile sensor or survey platforms. A flight altitude estimation system includes a logic device configured to communicate with a communication module and a flight barometer coupled to an unmanned aerial vehicle (UAV), wherein the communication module is configured to establish a communication link with a base station associated with the mobile platform, and the flight barometer is configured to provide flight pressures associated with the UAV as it maneuvers within a survey area. The logic device is configured to receive demark pressure data from a demark barometer coupled to the base station and determine a differential flight altitude estimation based, at least in part, on received flight pressure data and demark pressure data, a reference flight pressure and a reference demark pressure corresponding to a flight initiation location of the base station.

20 Claims, 8 Drawing Sheets



(58) **Field of Classification Search**
USPC 340/977
See application file for complete search history.

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WO	WO 2013/150442	10/2013
WO	WO 2015/102700	7/2015
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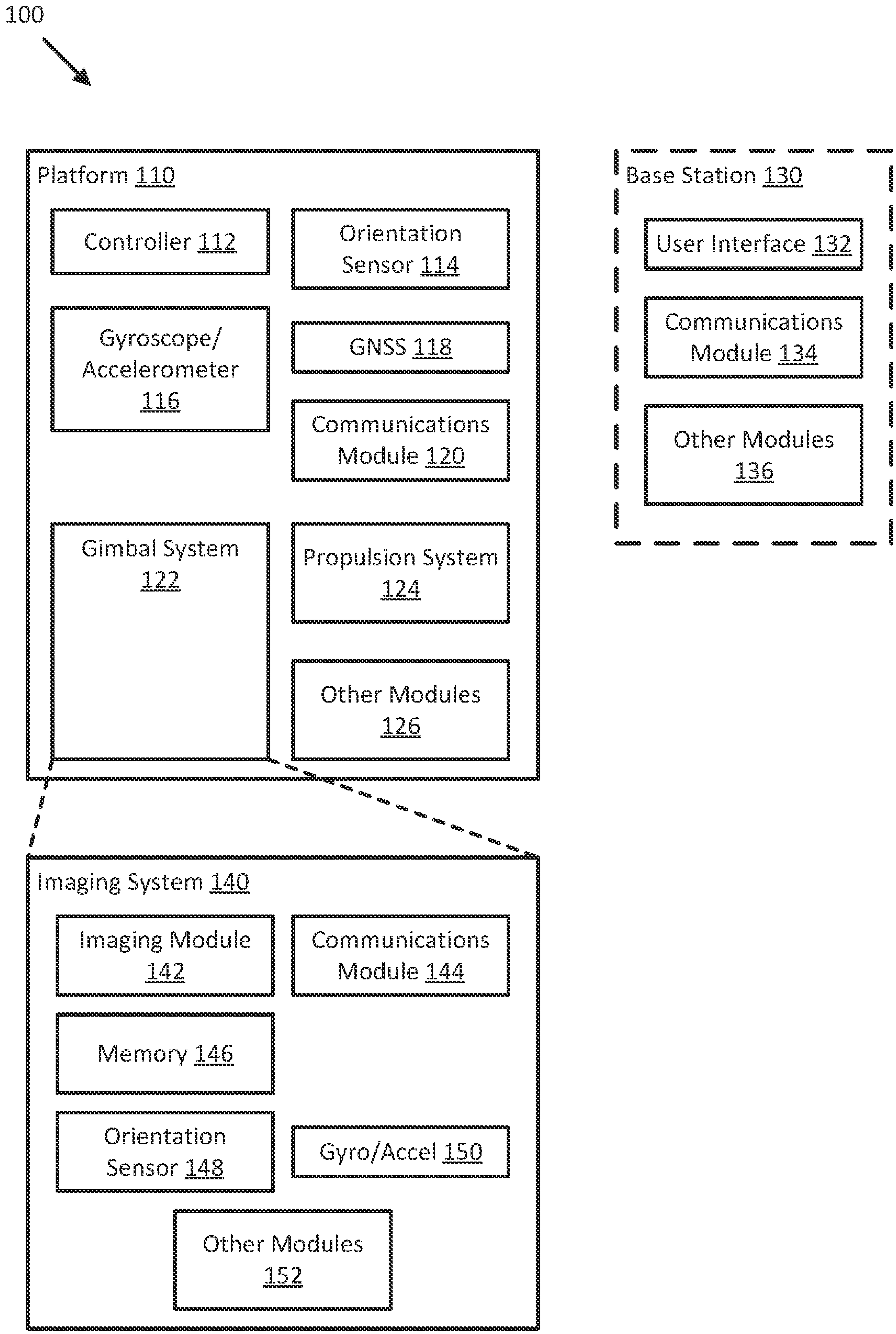
100
Platform 110
Controller 112
Orientation Sensor 114
Gyroscope/ Accelerometer 116
GNSS 118
Communications Module 120
Gimbal System 122
Propulsion System 124
Other Modules 126
Base Station 130
User Interface 132
Communications Module 134
Other Modules 136
Imaging System 140
Imaging Module 142
Communications Module 144
Memory 146
Orientation Sensor 148
Gyro/Accel 150
Other Modules 152

Fig. 1

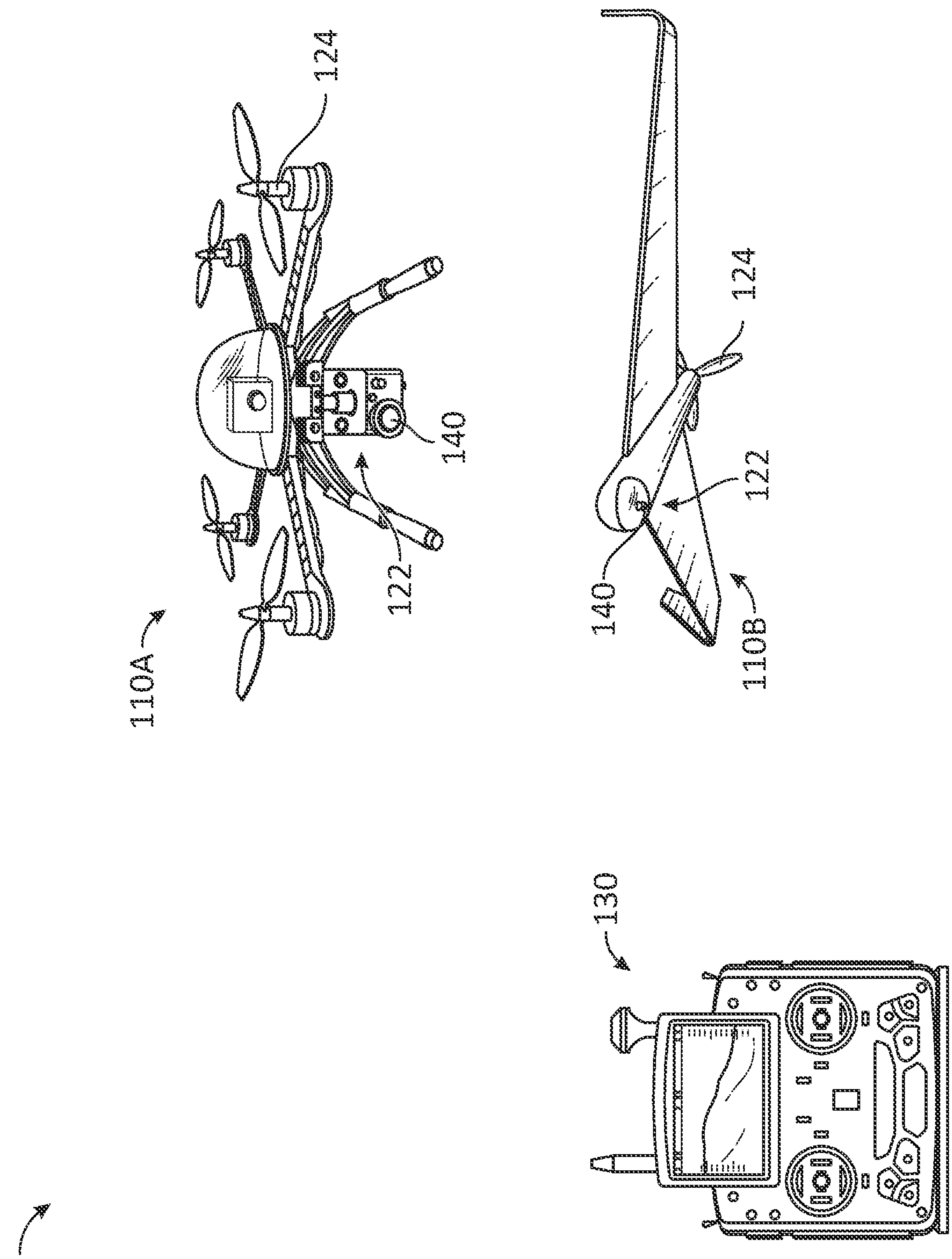

FIG. 2

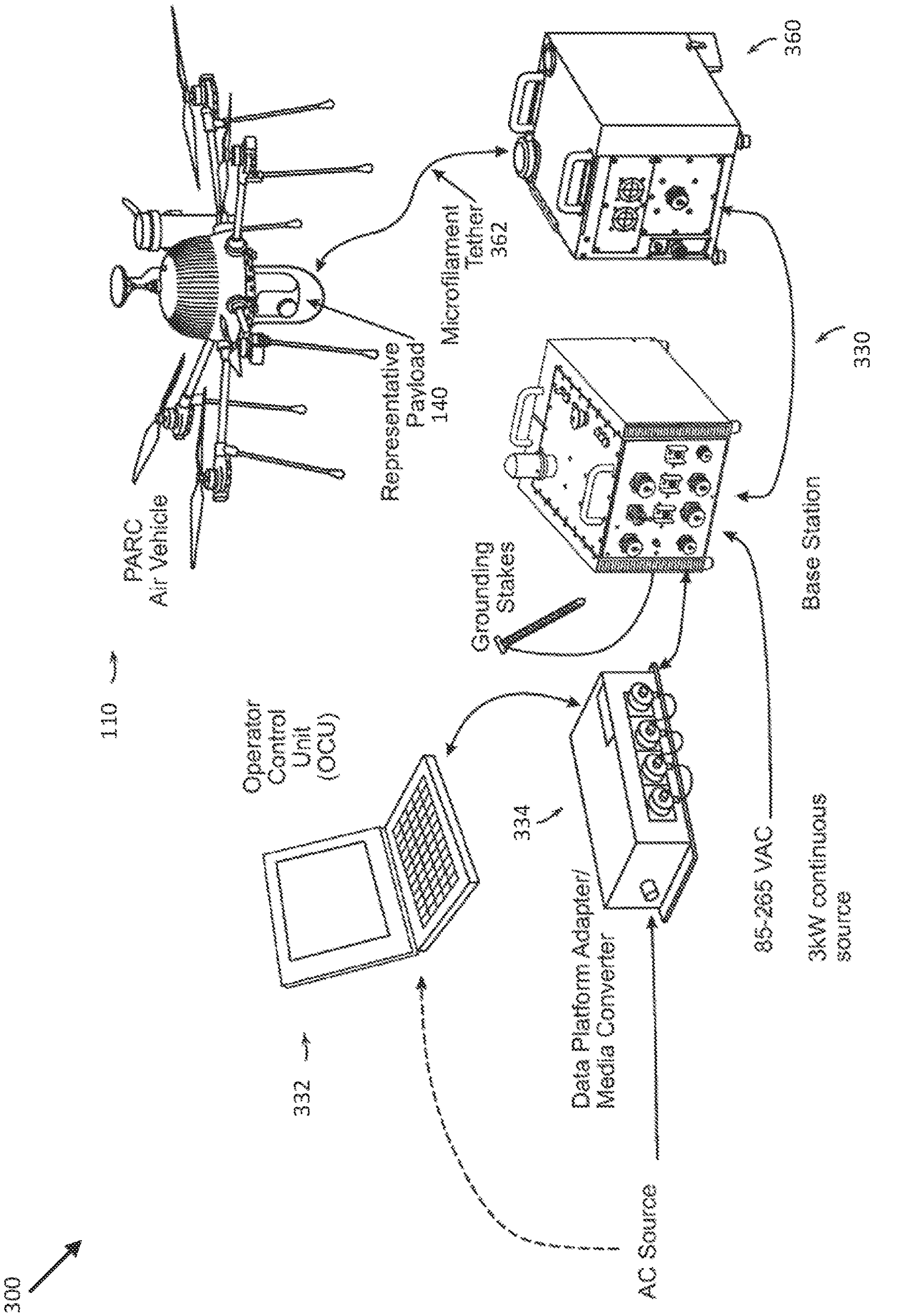
300
110
PARC
Air Vehicle
Representative
Payload
140
Microfilament
Tether
362
360
330
Base Station
Grounding
Stakes
Operator
Control
Unit
(OCU)
332
334
Data Platform Adapter/
Media Converter
AC Source
85-265 VAC
3kW continuous
source

Fig. 3A

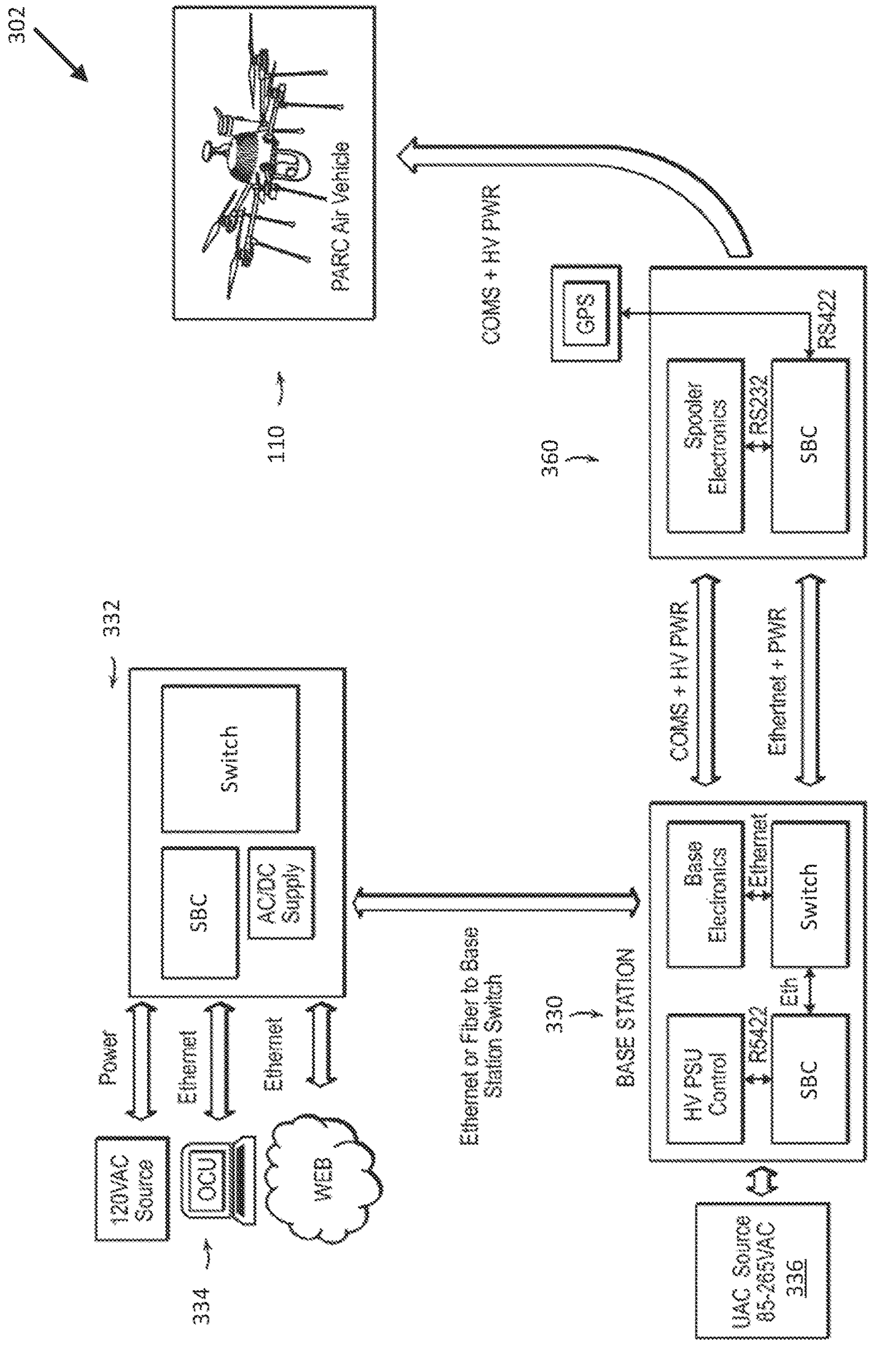
302
PARC Air Vehicle
110
COMS + HV PWR
GPS
RS422
Spooler Electronics
RS232
SBC
360
332
Switch
SBC
AC/DC Supply
COMS + HV PWR
Ethernet + PWR
Power
Ethernet
Ethernet
Ethernet or Fiber to Base Station Switch
330
BASE STATION
Base Electronics
Ethernet
Switch
Eth
HV PSU Control
RS422
SBC
120VAC Source
OCU
WEB
334
UAC Source 85-265VAC 336

Fig. 3B

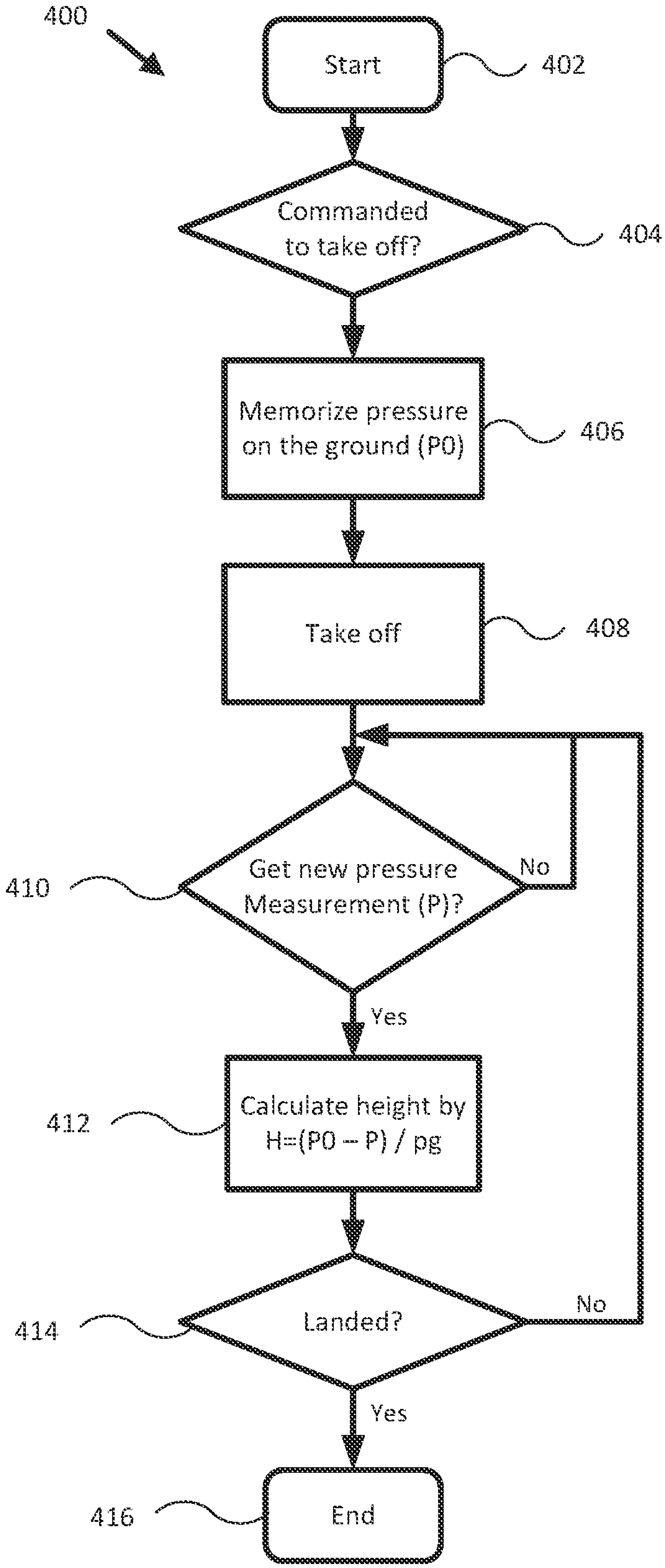
400
Start
402
Commanded to take off?
404
Memorize pressure on the ground (P0)
406
Take off
408
Get new pressure Measurement (P)?
410
No
Yes
Calculate height by H=(P0 – P) / ρg
412
Landed?
414
No
Yes
End
416

Fig. 4

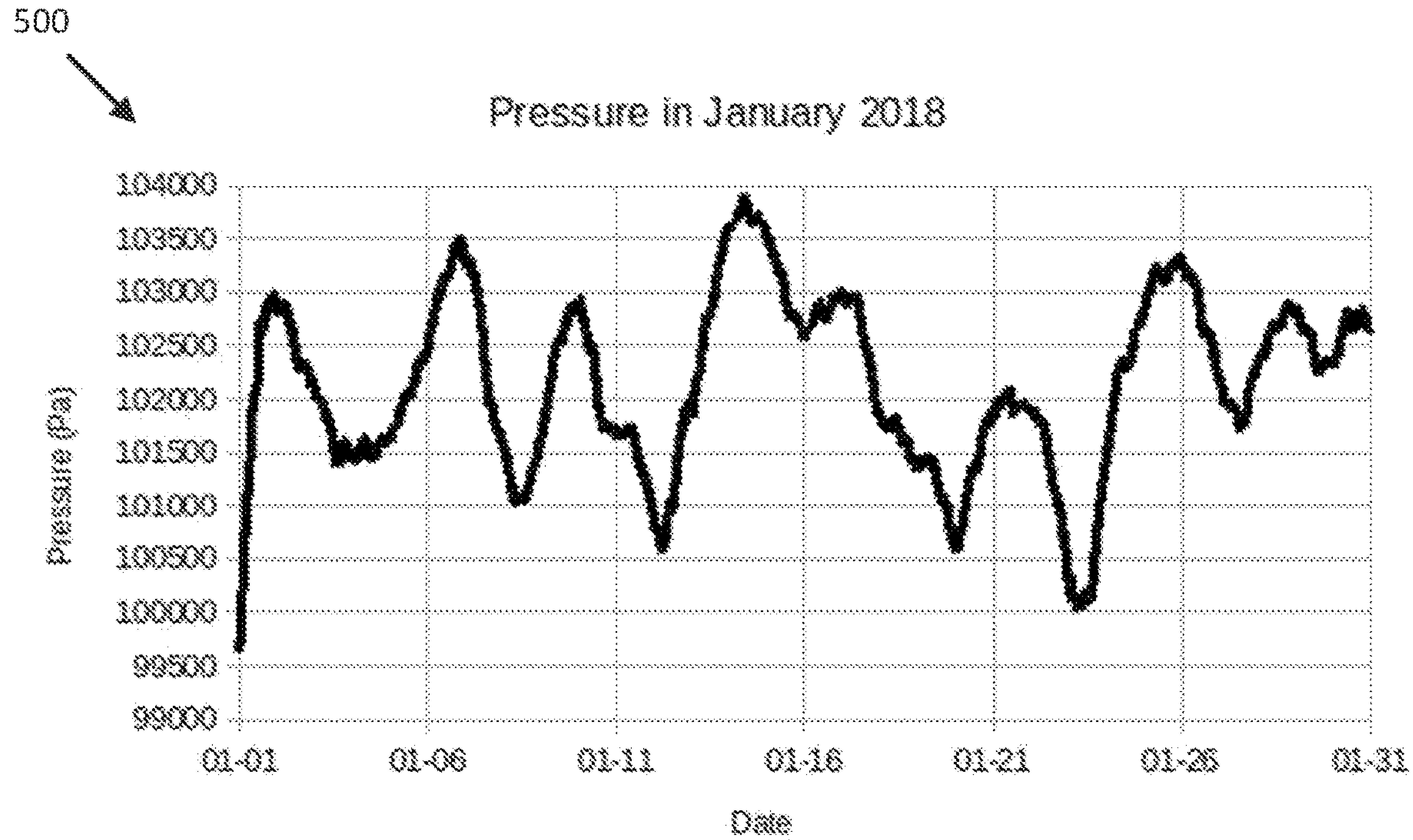
500
Pressure in January 2018
104000
103500
103000
102500
102000
101500
101000
100500
100000
99500
99000
Pressure (Pa)
01-01
01-06
01-11
01-16
01-21
01-26
01-31
Date

Fig. 5A

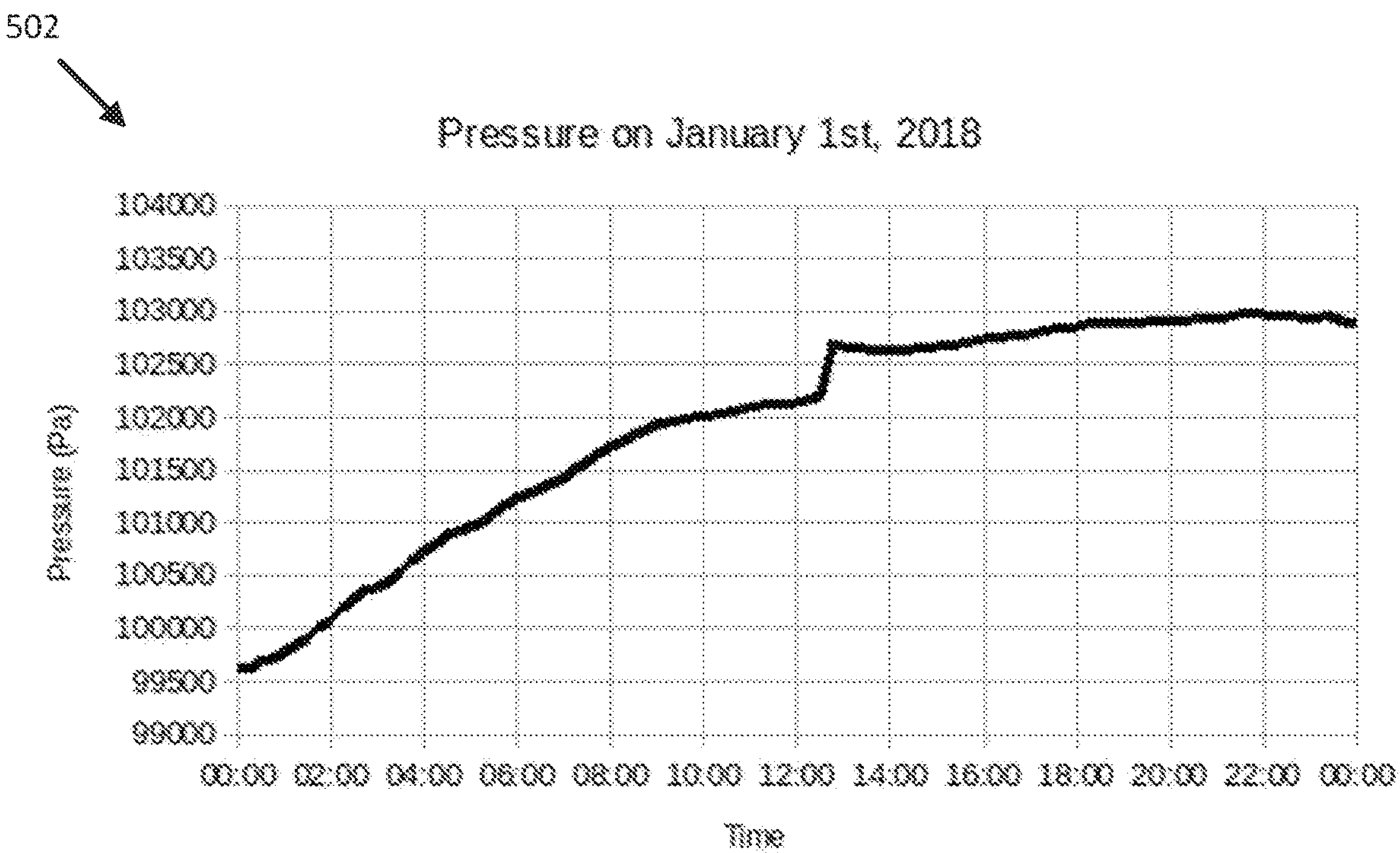
502
Pressure on January 1st, 2018
104000
103500
103000
102500
102000
101500
101000
100500
100000
99500
99000
Pressure (Pa)
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time

Fig. 5B

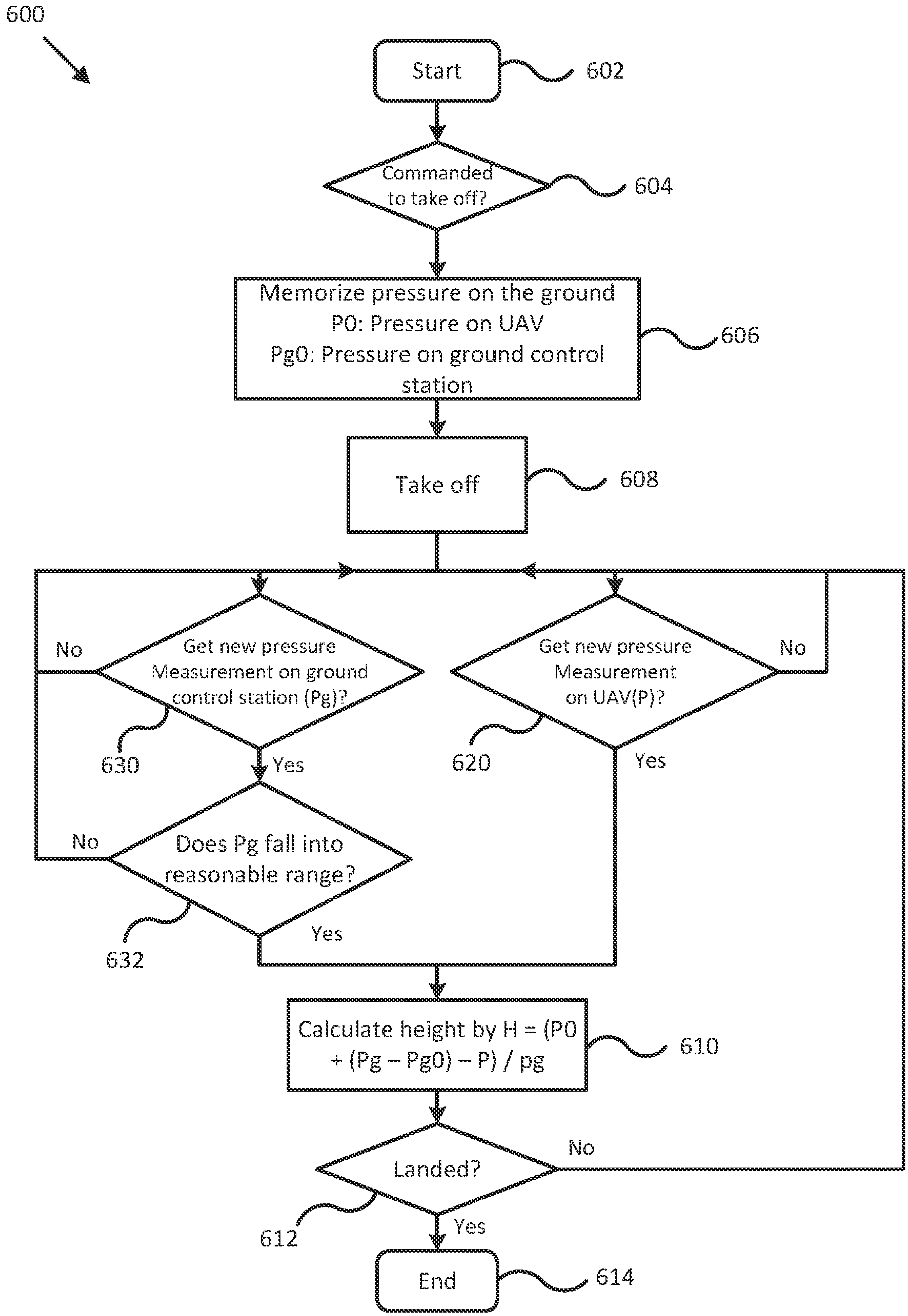
600
Start
602
Commanded to take off?
604
Memorize pressure on the ground
P0: Pressure on UAV
Pg0: Pressure on ground control station
606
Take off
608
Get new pressure Measurement on ground control station (Pg)?
No
630
Yes
Does Pg fall into reasonable range?
No
632
Yes
Get new pressure Measurement on UAV(P)?
No
620
Yes
Calculate height by H = (P0 + (Pg – Pg0) – P) / pg
610
Landed?
No
612
Yes
End
614

Fig. 6

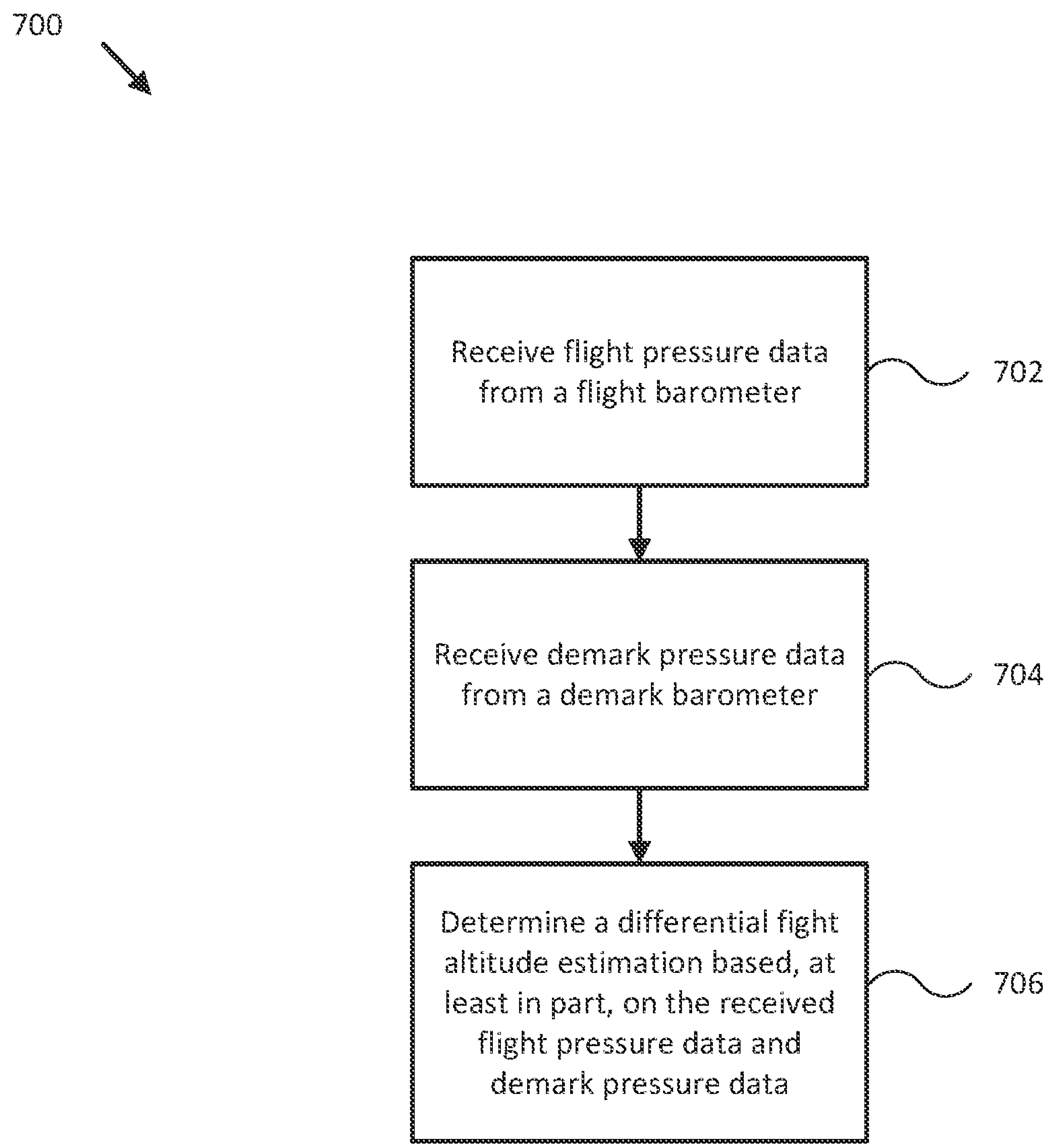
700
Receive flight pressure data from a flight barometer
702
Receive demark pressure data from a demark barometer
704
Determine a differential fight altitude estimation based, at least in part, on the received flight pressure data and demark pressure data
706

Fig. 7

FLIGHT ALTITUDE ESTIMATION SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of and priority to U.S. Provisional Patent Application No. 62/963,128 filed Jan. 19, 2020 and entitled "FLIGHT ALTITUDE ESTIMATION SYSTEMS AND METHODS," which is incorporated herein by reference in its entirety.

This application is related to International Patent Application No. PCT/US2019/025458 filed Apr. 2, 2019 and entitled "RADIO LINK COVERAGE MAP AND LOSS MITIGATION SYSTEMS AND METHODS," which is hereby incorporated by reference in its entirety. PCT/US2019/025458 claims the benefit of U.S. Provisional Patent Application No. 62/664,719 filed Apr. 30, 2018 and entitled "RADIO LINK COVERAGE MAP AND LOSS MITIGATION SYSTEMS AND METHODS" which is hereby incorporated by reference in its entirety.

This application is related to U.S. patent application Ser. No. 16/088,040 filed Sep. 24, 2018 and entitled "PERSISTENT AERIAL RECONNAISSANCE AND COMMUNICATION SYSTEM," which is hereby incorporated by reference in its entirety. U.S. patent application Ser. No. 16/088,040 is a 35 U.S.C. 371 national stage filing of PCT Patent Application No. PCT/US2017/024152 filed Mar. 24, 2017 and entitled "PERSISTENT AERIAL RECONNAISSANCE AND COMMUNICATION SYSTEM," which is hereby incorporated by reference in its entirety. PCT/US2017/024152 claims the benefit of U.S. Provisional patent Application No. 62/312,887 filed Mar. 24, 2016, U.S. Provisional Patent Application No. 62/315,873 filed Mar. 31, 2016, U.S. Provisional Patent Application No. 62/321,292 filed on Apr. 12, 2016, U.S. Provisional Patent Application No. 62/420,548 filed on Nov. 10, 2016, U.S. Provisional patent Application No. 62/463,536 filed on Feb. 24, 2017, all of which are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

The present invention relates generally to unmanned sensor platforms and, more particularly, to systems and methods for flight altitude estimation of unmanned aerial vehicles.

BACKGROUND

Modern unmanned sensor platforms, such as unmanned aerial vehicles (UAVs), remotely operated underwater vehicles (ROVs), unmanned (water) surface vehicles (USVs), and unmanned ground vehicles (UGVs) are able to operate over long distances and in all environments; rural, urban, and even underwater. Operation of such platforms typically includes real-time data transmissions between the unmanned sensor platform and a base station, which often includes a display to efficiently convey telemetry, imagery, and other sensor data captured by the platform to an operator. The operator, or a system incorporating such platforms, is often required to pilot or otherwise control or monitor an unmanned sensor platform throughout an entire mission relying solely on received data from the unmanned sensor platform. As such, non-automated or unreliably automated aspects related to safe and precise control of the unmanned

sensor platform can significantly reduce the operational flexibility of the platform and/or its constituent system.

Thus, there is a need in the art for methodologies to automate or more-reliably automate control of unmanned sensor platforms and increase the operational flexibility of such systems.

SUMMARY

Flight altitude estimation systems and related techniques are provided to improve the operation of unmanned aerial vehicles (UAVs) and/or unmanned aircraft systems (UASs) incorporating one or more such UAVs. One or more embodiments of the described flight altitude estimation systems may advantageously include a communication module to establish one or more wired and/or wireless communication links between a ground station and a UAV of the UAS, a flight barometer to measure and provide an atmospheric pressure corresponding to an estimated absolute altitude of the mobile platform, a controller to control operation of the communication module, the flight barometer, and/or the mobile platform, and one or more additional sensors to measure and provide sensor data corresponding to maneuvering and/or other operation of the mobile platform. In various embodiments, such additional sensors may include a remote sensor system configured to capture sensor data of a survey area from which a two and/or three dimensional spatial map of the survey area may be generated. For example, the mapping system may include one or more visible spectrum and/or infrared cameras and/or other remote sensor systems coupled to the UAV.

In one embodiment, a system includes a logic device configured to communicate with a communication module and a flight barometer coupled to an unmanned aerial vehicle (UAV), wherein the communication module is configured to establish a communication link with a base station associated with the mobile platform, the flight barometer is configured to provide flight pressures associated with the UAV as it maneuvers within a survey area. The logic device may be configured to receive flight pressure data from the flight barometer corresponding to one or more positions of the mobile platform within the survey area; receive demark pressure data from a demark barometer coupled to the base station; and determine a differential flight altitude estimation based, at least in part, on the received flight pressure data and demark pressure data, a reference flight pressure corresponding to a flight initiation location of the UAV, and a reference demark pressure corresponding to a flight initiation location of the base station.

In another embodiment, a method includes receiving flight pressure data from a flight barometer coupled to an unmanned aerial vehicle (UAV), wherein the flight barometer is configured to provide flight pressures associated with the UAV as it maneuvers within a survey area and the flight pressure data corresponds to one or more positions of the mobile platform within the survey area; receiving demark pressure data from a demark barometer coupled to the base station; and determining a differential flight altitude estimation based, at least in part, on the received flight pressure data and demark pressure data, a reference flight pressure corresponding to a flight initiation location of the UAV, and a reference demark pressure corresponding to a flight initiation location of the base station.

The scope of the invention is defined by the claims, which are incorporated into this section by reference. A more complete understanding of embodiments of the present invention will be afforded to those skilled in the art, as well as a realization of additional advantages thereof, by a consideration of the following detailed description of one or more embodiments. Reference will be made to the appended sheets of drawings that will first be described briefly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a diagram of an unmanned aircraft system (UAS) in accordance with an embodiment of the disclosure.

FIG. **2** illustrates a diagram of mobile platforms (UAVs) of a UAS in accordance with an embodiment of the disclosure.

FIG. **3**A illustrates a diagram of a UAS including a tethered UAV in accordance with an embodiment of the disclosure.

FIG. **3**B illustrates a diagram of communication and power interconnections for a UAS including a tethered UAV in accordance with an embodiment of the disclosure.

FIG. **4** illustrates a flow diagram of a control loop to determine a flight altitude estimate in accordance with an embodiment of the disclosure.

FIGS. **5**A-B illustrate graphs of atmospheric pressure trends.

FIG. **6** illustrates a flow diagram of a control loop to determine a flight altitude estimate in accordance with an embodiment of the disclosure.

FIG. **7** illustrates a flow diagram of various operations to provide flight altitude estimations for a UAS in accordance with an embodiment of the disclosure.

Embodiments of the present invention and their advantages are best understood by referring to the detailed description that follows. It should be appreciated that like reference numerals are used to identify like elements illustrated in one or more of the figures.

DETAILED DESCRIPTION

Flight altitude estimation systems and related techniques are provided to improve the operational flexibility and reliability of unmanned aircraft systems (UASs) including unmanned sensor platforms, such as unmanned aerial vehicles (UAVs). A flight altitude estimation system may advantageously include a communication module to establish one or more wired and/or wireless communication links between a ground station and a UAV of the UAS, a flight barometer to measure and provide an atmospheric pressure corresponding to an estimated absolute altitude of the mobile platform, a controller to control operation of the communication module, the flight barometer, and/or the mobile platform, and one or more additional sensors to measure and provide sensor data corresponding to maneuvering and/or other operation of the mobile platform. In various embodiments, such additional sensors may include a remote sensor system configured to capture sensor data of a survey area from which a two and/or three dimensional spatial map of the survey area may be generated. For example, the mapping system may include one or more visible spectrum and/or infrared cameras and/or other remote sensor systems coupled to the UAV.

Atmospheric pressure is a known source for estimating the altitude for a UAV. The conventional technique to estimate the above-ground height of a UAV involves using the difference between a live atmospheric pressure reading from a flight pressure sensor mounted the UAV and a non-live reference pressure that is the recorded pressure when the UAV left the ground. However, ambient atmospheric pressure is always changing due to temperature rise/drop, weather system movement, etc. Such changes are typically a relatively slow process compared to the time span of typical untethered UAV flights, so the assumption of a constant reference pressure is reasonable for flights lasting less than one hour, for example. By contrast, for tethered flight, which can be prolonged with continuous supply of power, the change of ambient pressure renders the recorded pressure at the ground relatively unreliable. For example, a 200 Pa pressure change, which can occur in a few hours even on a relatively calm day, equates to about a 20 meter height estimate drift.

Other sources for estimating height exist, but they are relatively unreliable and only mitigate the height drift issue rather than eliminate it. For example, an ultrasound/laser/lidar sensor or even computer vision usually has limited detecting range, typically less than 10 meters. Such detection is helpful when a UAV is close to the ground, but not when the UAV is tasked with hovering at a fixed altitude, or according to designated surveillance routes, high up in the air. Also, such sensors always provide relative measurements, which means they follow the elevation change of terrain, so if a UAV flies over a cliff or exits or enters a forest of trees, the altitude estimate can jump up/down dramatically and result in unstable flight control. Altitude estimates from GNSSs (Global Navigation Satellite Systems), such as GPS, GLONASS, Galileo, and Beidou, are not sufficiently accurate for reliable autonomous or assisted flight. For example, GPS altitude error can easily exceed 10 meters.

Atmospheric pressure can provide a reliable way to estimating flight altitude, but the reference pressure on the ground must be updated to compensate for drift. As such, embodiments described herein include a demark pressure sensor mounted to a ground control station or base station, which can provide live or substantially real time ambient reference pressures to a UAS. With such information, a relatively reliable flight altitude estimate may be determined based on the differential atmospheric pressure between a UAV and its associated base station, as described herein.

FIG. **1** illustrates a block diagram of UAS **100** in accordance with an embodiment of the disclosure. In some embodiments, system **100** may be configured to fly over a scene, through a structure, or approach a target and image or sense the scene, structure, or target, or portions thereof, using gimbal system **122** to aim imaging system/sensor payload **140** at the scene, structure, or target, or portions thereof. Resulting imagery and/or other sensor data may be processed (e.g., by sensor payload **140**, platform **110**, and/or base station **130**) and displayed to a user through use of user interface **132** (e.g., one or more displays such as a multi-function display (MFD), a portable electronic device such as a tablet, laptop, or smart phone, or other appropriate interface) and/or stored in memory for later viewing and/or analysis. In some embodiments, system **100** may be configured to use such imagery and/or sensor data to control operation of platform **110** and/or sensor payload **140**, as described herein, such as controlling gimbal system **122** to aim sensor payload **140** towards a particular direction or controlling propulsion system **124** to move platform **110** to a desired position in a scene or structure or relative to a target.

In the embodiment shown in FIG. **1**, UAS **100** includes platform **110**, optional base station **130**, and at least one imaging system/sensor payload **140**. Platform **110** may be a mobile platform configured to move or fly and position and/or aim sensor payload **140** (e.g., relative to a designated or detected target). As shown in FIG. **1**, platform **110** may include one or more of a controller **112**, an orientation sensor **114**, a gyroscope/accelerometer **116**, a global navigation satellite system (GNSS) **118**, a communications module **120**, a gimbal system **122**, a propulsion system **124**, and other modules **126**. Operation of platform **110** may be substantially autonomous and/or partially or completely controlled by optional base station **130**, which may include one or more of a user interface **132**, a communications module **134**, and other modules **136**. In other embodiments, platform **110** may include one or more of the elements of base station **130**, such as with various types of manned aircraft, terrestrial vehicles, and/or surface or subsurface watercraft. Sensor payload **140** may be physically coupled to platform **110** and be configured to capture sensor data (e.g., visible spectrum images, infrared images, narrow aperture radar data, and/or other sensor data) of a target position, area, and/or object(s) as selected and/or framed by operation of platform **110** and/or base station **130**. In some embodiments, one or more of the elements of system **100** may be implemented in a combined housing or structure that can be coupled to or within platform **110** and/or held or carried by a user of system **100**.

Controller **112** may be implemented as any appropriate logic device (e.g., processing device, microcontroller, processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA), memory storage device, memory reader, or other device or combinations of devices) that may be adapted to execute, store, and/or receive appropriate instructions, such as software instructions implementing a control loop for controlling various operations of platform **110** and/or other elements of system **100**, for example. Such software instructions may also implement methods for processing infrared images and/or other sensor signals, determining sensor information, providing user feedback (e.g., through user interface **132**), querying devices for operational parameters, selecting operational parameters for devices, or performing any of the various operations described herein (e.g., operations performed by logic devices of various devices of system **100**).

In addition, a non-transitory medium may be provided for storing machine readable instructions for loading into and execution by controller **112**. In these and other embodiments, controller **112** may be implemented with other components where appropriate, such as volatile memory, non-volatile memory, one or more interfaces, and/or various analog and/or digital components for interfacing with devices of system **100**. For example, controller **112** may be adapted to store sensor signals, sensor information, parameters for coordinate frame transformations, calibration parameters, sets of calibration points, and/or other operational parameters, over time, for example, and provide such stored data to a user using user interface **132**. In some embodiments, controller **112** may be integrated with one or more other elements of platform **110**, for example, or distributed as multiple logic devices within platform **110**, base station **130**, and/or sensor payload **140**.

In some embodiments, controller **112** may be configured to substantially continuously monitor and/or store the status of and/or sensor data provided by one or more elements of platform **110**, sensor payload **140**, and/or base station **130**, such as the position and/or orientation of platform **110**, sensor payload **140**, and/or base station **130**, for example, and the status of a communication link established between platform **110**, sensor payload **140**, and/or base station **130** (e.g., including packet loss of transmitted and received data between elements of system **100**, such as with digital communication links). In particular, packet loss is traditionally estimated as a percentage of packets lost vs packets sent to a designated target. However, controller **112** may also be configured to categorize packet loss, such as a simplified scaling methodology that may be used to categorize the amount of packet loss acceptable for a specific use of platform **110** and/or sensor payload **140**. Regardless, such communication links may be configured to be established and then transmit data between elements of system **100** substantially continuously throughout operation of system **100**, where such data includes various types of sensor data, control parameters, and/or other data.

Orientation sensor **114** may be implemented as one or more of a compass, float, accelerometer, and/or other device capable of measuring an orientation of platform **110** (e.g., magnitude and direction of roll, pitch, and/or yaw, relative to one or more reference orientations such as gravity and/or Magnetic North), gimbal system **122**, imaging system/sensor payload **140**, and/or other elements of system **100**, and providing such measurements as sensor signals and/or data that may be communicated to various devices of system **100**. Gyroscope/accelerometer **116** may be implemented as one or more electronic sextants, semiconductor devices, integrated chips, accelerometer sensors, accelerometer sensor systems, or other devices capable of measuring angular velocities/accelerations and/or linear accelerations (e.g., direction and magnitude) of platform **110** and/or other elements of system **100** and providing such measurements as sensor signals and/or data that may be communicated to other devices of system **100** (e.g., user interface **132**, controller **112**).

GNSS **118** may be implemented according to any global navigation satellite system, including a GPS, GLONASS, and/or Galileo based receiver and/or other device capable of determining absolute and/or relative position of platform **110** (e.g., or an element of platform **110**) based on wireless signals received from space-born and/or terrestrial sources (e.g., eLoran, and/or other at least partially terrestrial systems), for example, and capable of providing such measurements as sensor signals and/or data (e.g., coordinates) that may be communicated to various devices of system **100**. In some embodiments, GNSS **118** may include an altimeter, for example, or may be used to provide an absolute altitude.

Communications module **120** may be implemented as any wired and/or wireless communications module configured to transmit and receive analog and/or digital signals between elements of system **100**. For example, communications module **120** may be configured to receive flight control signals and/or data from base station **130** and provide them to controller **112** and/or propulsion system **124**. In other embodiments, communications module **120** may be configured to receive images and/or other sensor information (e.g., visible spectrum and/or infrared still images or video images) from sensor payload **140** and relay the sensor data to controller **112** and/or base station **130**. In some embodiments, communications module **120** may be configured to support spread spectrum transmissions, for example, and/or multiple simultaneous communications channels between elements of system **100**. Wireless communication links may include one or more analog and/or digital radio communication links, such as WiFi and others, as described herein, and may be direct communication links established between elements of system **100**, for example, or may be relayed through one or more wireless relay stations configured to receive and retransmit wireless communications.

In some embodiments, communications module **120** may be configured to monitor the status of a communication link established between platform **110**, sensor payload **140**, and/

or base station **130** (e.g., including packet loss of transmitted and received data between elements of system **100**, such as with digital communication links). Such status information may be provided to controller **112**, for example, or transmitted to other elements of system **100** for monitoring, storage, or further processing, as described herein. In particular, communications module **120** may be configured to monitor packet loss of communications between platform **110** and base station **130** and/or categorize such packet loss according to an acceptable level of packet loss for a particular use or application associated with operation and/or a status of platform **110** and/or other elements of system **100**. Regardless, communication links established by communication module **120** may be configured to transmit data between elements of system **100** substantially continuously throughout operation of system **100**, where such data includes various types of sensor data, control parameters, and/or other data, as described herein.

In some embodiments, gimbal system **122** may be implemented as an actuated gimbal mount, for example, that may be controlled by controller **112** to stabilize sensor payload **140** relative to a target or to aim sensor payload **140** according to a desired direction and/or relative position. As such, gimbal system **122** may be configured to provide a relative orientation of sensor payload **140** (e.g., relative to an orientation of platform **110**) to controller **112** and/or communications module **120** (e.g., gimbal system **122** may include its own orientation sensor **114**). In other embodiments, gimbal system **122** may be implemented as a gravity driven mount (e.g., non-actuated). In various embodiments, gimbal system **122** may be configured to provide power, support wired communications, and/or otherwise facilitate operation of articulated sensor/sensor payload **140**. In further embodiments, gimbal system **122** may be configured to couple to a laser pointer, range finder, and/or other device, for example, to support, stabilize, power, and/or aim multiple devices (e.g., sensor payload **140** and one or more other devices) substantially simultaneously.

Propulsion system **124** may be implemented as one or more propellers, turbines, or other thrust-based propulsion systems, and/or other types of propulsion systems that can be used to provide motive force and/or lift to platform **110** and/or to steer platform **110**. In some embodiments, propulsion system **124** may include multiple propellers (e.g., a tri, quad, hex, oct, or other type "copter") that can be controlled (e.g., by controller **112**) to provide lift and motion for platform **110** and to provide an orientation for platform **110**. In other embodiments, propulsion system **110** may be configured primarily to provide thrust while other structures of platform **110** provide lift, such as in a fixed wing embodiment (e.g., where wings provide the lift) and/or an aerostat embodiment (e.g., balloons, airships, hybrid aerostats). In various embodiments, propulsion system **124** may be implemented with a portable power supply, such as a battery and/or a combustion engine/generator and fuel supply.

Other modules **126** may include other and/or additional sensors, actuators, communications modules/nodes, and/or user interface devices, for instance, and may be used to provide additional environmental information related to operation of platform **110**, for example. In some embodiments, other modules **126** may include a humidity sensor, a wind and/or water temperature sensor, a barometer (e.g., a flight barometer), an altimeter, a radar system, a proximity sensor, a visible spectrum camera or infrared camera (with an additional mount), an irradiance detector, and/or other environmental sensors providing measurements and/or other sensor signals that can be displayed to a user and/or used by other devices of system **100** (e.g., controller **112**) to provide operational control of platform **110** and/or system **100**.

In some embodiments, other modules **126** may include one or more actuated and/or articulated devices (e.g., multi-spectrum active illuminators, visible and/or IR cameras, radars, sonars, and/or other actuated devices) coupled to platform **110**, where each actuated device includes one or more actuators adapted to adjust an orientation of the device, relative to platform **110**, in response to one or more control signals (e.g., provided by controller **112**). In particular, other modules **126** may include a stereo vision system configured to provide image data that may be used to calculate or estimate a position of platform **110**, for example, or to calculate or estimate a relative position of a navigational hazard in proximity to platform **110**. In various embodiments, controller **130** may be configured to use such proximity and/or position information to help safely pilot platform **110** and/or monitor communication link quality, as described herein. One or more such cameras/vision systems (e.g., other modules **126**) may be used as a position sensor and configured to provide a position of platform **110** via visual odometry, simultaneous localization and mapping (SLAM), and/or other techniques, as a supplement and/or alternative to GNSS **118**, such as when GNSS signals are effective blocked or jammed by walls, buildings, and/or environmental electromagnetic noise.

User interface **132** of base station **130** may be implemented as one or more of a display, a touch screen, a keyboard, a mouse, a joystick, a knob, a steering wheel, a yoke, and/or any other device capable of accepting user input and/or providing feedback to a user. In various embodiments, user interface **132** may be adapted to provide user input (e.g., as a type of signal and/or sensor information transmitted by communications module **134** of base station **130**) to other devices of system **100**, such as controller **112**. User interface **132** may also be implemented with one or more logic devices (e.g., similar to controller **112**) that may be adapted to store and/or execute instructions, such as software instructions, implementing any of the various processes and/or methods described herein. For example, user interface **132** may be adapted to form communication links, transmit and/or receive communications (e.g., infrared images and/or other sensor signals, control signals, sensor information, user input, and/or other information), for example, or to perform various other processes and/or methods described herein.

In one embodiment, user interface **132** may be adapted to display a time series of various sensor information and/or other parameters as part of or overlaid on a graph or map, which may be referenced to a position and/or orientation of platform **110** and/or other elements of system **100**. For example, user interface **132** may be adapted to display a time series of positions, headings, and/or orientations of platform **110** and/or other elements of system **100** overlaid on a geographical map, which may include one or more graphs indicating a corresponding time series of actuator control signals, sensor information, and/or other sensor and/or control signals.

In some embodiments, user interface **132** may be adapted to accept user input including a user-defined target heading, waypoint, route, and/or orientation for an element of system **100**, for example, and to generate control signals to cause platform **110** to move according to the target heading, route, and/or orientation, or to aim sensor payload **140** accordingly. In other embodiments, user interface **132** may be adapted to accept user input modifying a control loop parameter of controller **112**, for example.

In further embodiments, user interface **132** may be adapted to accept user input including a user-defined target attitude, orientation, and/or position for an actuated or articulated device (e.g., sensor payload **140**) associated with platform **110**, for example, and to generate control signals for adjusting an orientation and/or position of the actuated device according to the target attitude, orientation, and/or position. Such control signals may be transmitted to controller **112** (e.g., using communications modules **134** and **120**), which may then control platform **110** accordingly.

Communications module **134** may be implemented as any wired and/or wireless communications module configured to transmit and receive analog and/or digital signals between elements of system **100**. For example, communications module **134** may be configured to transmit flight control signals from user interface **132** to communications module **120** or **144**. In other embodiments, communications module **134** may be configured to receive sensor data (e.g., visible spectrum and/or infrared still images or video images, or other sensor data) from sensor payload **140**. In some embodiments, communications module **134** may be configured to support spread spectrum transmissions, for example, and/or multiple simultaneous communications channels between elements of system **100**. In various embodiments, communications module **134** may be configured to monitor the status of a communication link established between base station **130**, sensor payload **140**, and/or platform **110** (e.g., including packet loss of transmitted and received data between elements of system **100**, such as with digital communication links), as described herein. Such status information may be provided to user interface **132**, for example, or transmitted to other elements of system **100** for monitoring, storage, or further processing, as described herein.

Other modules **136** of base station **130** may include other and/or additional sensors, actuators, communications modules/nodes, and/or user interface devices used to provide additional environmental information associated with base station **130**, for example. In some embodiments, other modules **136** may include a humidity sensor, a wind and/or water temperature sensor, a barometer (e.g., a demark barometer), a radar system, a visible spectrum camera, an infrared camera, a GNSS, and/or other environmental sensors providing measurements and/or other sensor signals that can be displayed to a user and/or used by other devices of system **100** (e.g., controller **112**) to provide operational control of platform **110** and/or system **100** or to process sensor data to compensate for environmental conditions, such as an water content in the atmosphere approximately at the same altitude and/or within the same area as platform **110** and/or base station **130**, for example. In some embodiments, other modules **136** may include one or more actuated and/or articulated devices (e.g., multi-spectrum active illuminators, visible and/or IR cameras, radars, sonars, and/or other actuated devices), where each actuated device includes one or more actuators adapted to adjust an orientation of the device in response to one or more control signals (e.g., provided by user interface **132**).

In embodiments where imaging system/sensor payload **140** is implemented as an imaging device, imaging system/sensor payload **140** may include imaging module **142**, which may be implemented as a cooled and/or uncooled array of detector elements, such as visible spectrum and/or infrared sensitive detector elements, including quantum well infrared photodetector elements, bolometer or microbolometer based detector elements, type II superlattice based detector elements, and/or other infrared spectrum detector elements that can be arranged in a focal plane array. In various embodiments, imaging module **142** may include one or more logic devices (e.g., similar to controller **112**) that can be configured to process imagery captured by detector elements of imaging module **142** before providing the imagery to memory **146** or communications module **144**. More generally, imaging module **142** may be configured to perform any of the operations or methods described herein, at least in part, or in combination with controller **112** and/or user interface **132**.

In some embodiments, sensor payload **140** may be implemented with a second or additional imaging modules similar to imaging module **142**, for example, that may include detector elements configured to detect other electromagnetic spectrums, such as visible light, ultraviolet, and/or other electromagnetic spectrums or subsets of such spectrums. In various embodiments, such additional imaging modules may be calibrated or registered to imaging module **142** such that images captured by each imaging module occupy a known and at least partially overlapping field of view of the other imaging modules, thereby allowing different spectrum images to be geometrically registered to each other (e.g., by scaling and/or positioning). In some embodiments, different spectrum images may be registered to each other using pattern recognition processing in addition or as an alternative to reliance on a known overlapping field of view.

Communications module **144** of sensor payload **140** may be implemented as any wired and/or wireless communications module configured to transmit and receive analog and/or digital signals between elements of system **100**. For example, communications module **144** may be configured to transmit infrared images from imaging module **142** to communications module **120** or **134**. In other embodiments, communications module **144** may be configured to receive control signals (e.g., control signals directing capture, focus, selective filtering, and/or other operation of sensor payload **140**) from controller **112** and/or user interface **132**. In some embodiments, communications module **144** may be configured to support spread spectrum transmissions, for example, and/or multiple simultaneous communications channels between elements of system **100**. In various embodiments, communications module **144** may be configured to monitor the status of a communication link established between sensor payload **140**, base station **130**, and/or platform **110** (e.g., including packet loss of transmitted and received data between elements of system **100**, such as with digital communication links), as described herein. Such status information may be provided to imaging module **142**, for example, or transmitted to other elements of system **100** for monitoring, storage, or further processing, as described herein.

Memory **146** may be implemented as one or more machine readable mediums and/or logic devices configured to store software instructions, sensor signals, control signals, operational parameters, calibration parameters, infrared images, and/or other data facilitating operation of system **100**, for example, and provide it to various elements of system **100**. Memory **146** may also be implemented, at least in part, as removable memory, such as a secure digital memory card for example including an interface for such memory.

Orientation sensor **148** of sensor payload **140** may be implemented similar to orientation sensor **114** or gyroscope/accelerometer **116**, and/or any other device capable of measuring an orientation of sensor payload **140**, imaging module **142**, and/or other elements of sensor payload **140** (e.g., magnitude and direction of roll, pitch, and/or yaw, relative to one or more reference orientations such as gravity and/or Magnetic North) and providing such measurements as sensor signals that may be communicated to various devices of system **100**. Gyroscope/accelerometer (e.g., angular motion sensor) **150** of sensor payload **140** may be implemented as one or more electronic sextants, semiconductor devices, integrated chips, accelerometer sensors, accelerometer sensor systems, or other devices capable of measuring angular velocities/accelerations (e.g., angular motion) and/or linear accelerations (e.g., direction and magnitude) of sensor payload **140** and/or various elements of sensor payload **140** and providing such measurements as sensor signals that may be communicated to various devices of system **100**.

Other modules **152** of sensor payload **140** may include other and/or additional sensors, actuators, communications modules/nodes, cooled or uncooled optical filters, and/or user interface devices used to provide additional environmental information associated with sensor payload **140**, for example. In some embodiments, other modules **152** may include a humidity sensor, a wind and/or water temperature sensor, a barometer (e.g., a payload barometer), a radar system, a visible spectrum camera, an infrared camera, a GNSS, and/or other environmental sensors providing measurements and/or other sensor signals that can be displayed to a user and/or used by imaging module **142** or other devices of system **100** (e.g., controller **112**) to provide operational control of platform **110** and/or system **100** or to process imagery to compensate for environmental conditions.

In general, each of the elements of system **100** may be implemented with any appropriate logic device (e.g., processing device, microcontroller, processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA), memory storage device, memory reader, or other device or combinations of devices) that may be adapted to execute, store, and/or receive appropriate instructions, such as software instructions implementing a method for providing sensor data and/or imagery, for example, or for transmitting and/or receiving communications, such as sensor signals, sensor information, and/or control signals, between one or more devices of system **100**.

In addition, one or more non-transitory mediums may be provided for storing machine readable instructions for loading into and execution by any logic device implemented with one or more of the devices of system **100**. In these and other embodiments, the logic devices may be implemented with other components where appropriate, such as volatile memory, non-volatile memory, and/or one or more interfaces (e.g., inter-integrated circuit (I2C) interfaces, mobile industry processor interfaces (MIPI), joint test action group (JTAG) interfaces (e.g., IEEE 1149.1 standard test access port and boundary-scan architecture), and/or other interfaces, such as an interface for one or more antennas, or an interface for a particular type of sensor).

Sensor signals, control signals, and other signals may be communicated among elements of system **100** using a variety of wired and/or wireless communication techniques, including voltage signaling, Ethernet, WiFi, Bluetooth, Zigbee, Xbee, Micronet, or other medium and/or short range wired and/or wireless networking protocols and/or implementations, for example. In such embodiments, each element of system **100** may include one or more modules supporting wired, wireless, and/or a combination of wired and wireless communication techniques. In some embodiments, various elements or portions of elements of system **100** may be integrated with each other, for example, or may be integrated onto a single printed circuit board (PCB) to reduce system complexity, manufacturing costs, power requirements, coordinate frame errors, and/or timing errors between the various sensor measurements.

Each element of system **100** may include one or more batteries, capacitors, or other electrical power storage devices, for example, and may include one or more solar cell modules or other electrical power generating devices. In some embodiments, one or more of the devices may be powered by a power source for platform **110**, using one or more power leads. Such power leads may also be used to support one or more communication techniques between elements of system **100**.

FIG. **2** illustrates a diagram of mobile platforms (UAVs) **110**A and **110**B of UAS **200** including imaging systems/sensor payloads **140** and associated gimbal systems **122** in accordance with an embodiment of the disclosure. In the embodiment shown in FIG. **2**, UAS **200** includes base station **130**, UAV **110**A with articulated imaging system/sensor payload **140** and gimbal system **122**, and UAV **110**B with articulated imaging system/sensor payload **140** and gimbal system **122**, where base station **130** may be configured to control motion, position, and/or orientation of UAV **110**A, UAV **110**B, and/or sensor payloads **140**.

Many UAVs are designed to fly or hover during their reconnaissance or observation missions while powered by an onboard battery that is required to supply power for propulsion, onboard sensors, and other electronics. The battery life therefore provides a maximum mission length for the UAV. Other UAVs may be configured to be powered via a microfilament deployed from a ground location during their operation thereby extending mission length while restricting the mission flight area in most cases based on the length of the filament. Embodiments described herein may include controlled operation of tethered UAVs with which power, control, and communication signals are transmitted to the UAV. The control station (e.g., base station **130**) and UAV include power management systems and control circuits to control takeoff, flight operation, and landing of the UAV. One or more controllers located with the control station, on the UAV or connected by a communications network are configured to execute instructions to operate the system. In one embodiment, a UAV may draw power from remote sources (via tether), from on-board batteries, or from both, as required by operator command or by autonomous control. This ability allows, among other features, a ground or water based UAV to have a power source for safe, controlled landings upon interruption of a tethered power source.

Various embodiments of a UAS, as described herein, include a tether management system having a relatively high tether deployment and retrieval rate. A static assembly can be used on which the tether can be positioned for deployment and retrieval. A moveable actuator may contact the tether to separate the tether from the static assembly during deployment or retrieval in response to commands from a control system that responds to both manual and stored instructions to coordinate tether management with UAV flight control functions.

In some embodiments, a UAS incorporating a tethered UAV may be referred to as a Persistent Aerial Reconnaissance and Communication (PARC) System that offers extended flight time for the UAV through the use of microfilament, which may be implemented by a pair of threadlike wires that can transmit over a kilowatt of power to the UAV while also enabling transmission of bi-directional control and or sensor data, including high-definition video. A PARC system may be rapidly deployed as a low-maintenance UAV based UAS that allows cameras, radios, or other payloads to remain in operation for long durations. A PARC system may be designed to be intuitively simple to launch/land, and a small logistics footprint may make the system appropriate for austere environments. A PARC system may require minimal training for operations and maintenance. A PARC system may be designed for quick and simplified deployment to minimize operator management while maximizing capability provided in terms of communications extension, force protection, persistent stare, and tactical intelligence.

FIG. **3**A illustrates a diagram of a UAS **300** including a tethered UAV **110** in accordance with an embodiment of the disclosure. In some embodiments, UAS **300** may be implemented as a PARC system. UAS **300** includes tethered UAV **110** equipped with a payload **140**, a tether management system **360**, and a base station **330**. UAS **300** may also include a data platform adapter/media converter (DPA/MC) **334** that is coupled to an operator control unit (OCU) **332**. Payload **140** may be a camera, radar, or other type of surveillance, communication, or other sensor required by a particular application of the PARC system. In general, system **300** may be an embodiment of system **100** of FIG. **1**, where each of base station **330**, OCU **332**, DPA/MC **334**, and/or tether management system **360** may be elements of base station **130** (e.g., and/or other modules **136**) of system **100**.

Tether management system **360** may be a ground based component that includes a spool assembly that houses a tether spool assembly, which may be a cylindrical hub that holds a pre-wound amount of micro-filament tether to be attached to UAV **110**. For example, in one embodiment, the spool assembly may hold 167.6 meters (550 feet) of micro-filament tether. In one embodiment, the micro-filament tether may be Kevlar-jacketed twisted copper pair with insulation that provides both a power link and a communication link between tether management system **360** and UAV **110**. Base station **330** may be connected to tether management system **360**. Base station **330** may include an assembly that houses an AC power input and high voltage conversion electronics in an environmentally sealed enclosure. Base station **330** may also include a high voltage output port to supply high voltage to tether management system **360**, which delivers the high voltage via the micro-filament to UAV **110**. A data platform adapter/media converter (DPA/MC) **334** may serve the function of connecting OCU **332** to base station **330** while also providing electrical shock hazard isolation. DPA/MC **334** may include an optical port to connect to base station **330** via a fiber optic cable and may also include an Ethernet port to connect to OCU **332**. OCU **332** may be a ruggedized laptop or other computing device equipped with and able to execute an OCU application enabling control of UAV **110**. Further details regarding the operation of tethered and untethered vehicles can be found in U.S. Pat. Nos. 7,510,142 and 7,631,834, the entire contents of which are incorporated herein by reference.

FIG. **3**B illustrates a diagram of communication and power interconnections for UAS **300** in accordance with an embodiment of the disclosure. As shown in FIG. **3**B, base station **330** may convert power (e.g., provided by source **336**) to high voltage power and provide high voltage power to tether management system **360**. Base station **330** may also provide a communication link over Ethernet and low voltage power to tether management system **360**. Tether management system **360** may provide the high voltage power over the microfilament tether to UAV **110** for use for energy intensive operations such as radar sensing and propulsion during flight operations. As noted above, the microfilament may also provide a communication pathway used to communicate with UAV **110** by an operator of OCU **332** and/or UAS **300**. DPA/MC **334** may communicate with base station **330** over an optical fiber and communicate with OCU **332** over an Ethernet connection.

For UAVs, especially quadcopters, which are not able or permitted to ascend very high, the height above ground level (AGL) is generally more important than altitude/elevation above sea level (ASL) (e.g., the absolute altitude), due to risk of collision with trees and/or buildings that project from and are therefore referenced to the local ground altitude.

A substantially real time flight altitude may be estimated based on real time measurements of atmospheric pressure using a flight barometer mounted to the UAV and Pascal's Law: $\Delta P=\rho g\Delta h$, where ΔP is the difference in pressure between the flight pressure at the UAV and a reference demark pressure (given in pascals in the SI system) at the ground station; ρ is the (average) local air density (in kilograms per cubic meter in the SI system); g is acceleration due to gravity (in meters per second squared in the SI system); and Δh is the difference in elevation between the same two positions (of the UAV and the ground station) used to determine ΔP (in meters in the SI system). However, if the reference demark pressure is assumed to be constant, such determination is subject to significant drift when the UAV is aloft for relatively long periods of time (e.g., beyond 0.5 hours or more).

For example, the take-off position (home position) may be used as the position to measure the reference demark pressure, and that reference demark pressure may be provided by either the flight barometer or the demark barometer and stored before take-off. Under such conditions, the flight altitude or height estimate is: $H=(P0-P)/\rho g$, where H is the flight altitude estimate; P**0** is the reference demark pressure; P is the ambient flight pressure measured at the UAV from the flight barometer; ρ (the local air density) can be set to a proper value or calculated by P/RT, where the gas constant for dry air R=287.058 J/(kg·K) and T is the ambient temperature in K; and g is set to 9.81 m/s2. An example flow diagram of a control loop **400** to determine a flight altitude estimate, where the reference demark pressure is assumed to be constant, is provided in FIG. **4**.

In particular, block **402** of control loop **400** represents initiation of execution of control loop **400** (e.g., by controller **112** of UAV **110** and/or user interface **132** of base station **130** or OCU **332**), which may include initializing a fight barometer mounted to UAV **110**. Block **404** represents a delay of further execution until UAV **110** receives or generates a flight initiation command (e.g., to take off at or near base station **130**/**330**). In block **406**, UAV **110** receives a ground or reference flight pressure measurement P**0** from the flight barometer coupled to UAV **110** after the flight initiation command is received or generated and before flight initiation commences, for example, and stores the ground or reference flight pressure measurement P**0**. In block **408**, UAV **110** determines it has initiated flight, such as by evaluating telemetry from various sensors, for example, and proceeds to block **410**.

In block **410**, periodic flight pressure measurements P are made using the flight barometer based on various criteria, such as reaching a preset maximum time duration between flight pressure measurements, reaching a designated waypoint in a planned route, and/or during a relatively complex maneuver, where the flight pressure measurements may be made at approximately the maximum rate supported by the flight barometer and/or various elements of system **100**. In block **412**, a flight altitude estimation H is determined based on the stored ground or reference fight pressure measurement P**0** and the most recent flight pressure measurement P. In some embodiments, such flight altitude estimation may be used for autopiloting UAV **110** and/or stored for later telemetry graphing or mapping, for example, and/or may be communicated to base station **130/330** as telemetry data for remote storage and/or display to an operator of system **100**. In block **414**, UAV **110** determines whether it has completed a flight or landed, such as by evaluating telemetry from various sensors, for example, and either continues to iteratively execute blocks **410-414** (e.g., while still in flight or executing a planned route), or proceeds to block **416**, which represents ending execution of control loop **400**.

Such method can work well for relatively short flights (e.g., lasting less than 0.5 or 1 hours). However, ambient pressure is always changing. For example, FIGS. **5**A-B show graphs of atmospheric pressure trends in Waterloo Ontario Canada in January 2018. Looking at January 1 as an example, the atmospheric pressure rose from 99600 Pa to 100100 Pa in the first 2 hours of the day (ambient temperature was approximately 5° C.). If a UAV took off at 12:00 am, quickly ascended to 100 m, and maintained that height for 2 hours, it would drift to an actual flight altitude of 140.7 m above the ground at 2:00 am due to reference pressure change:

$$\begin{aligned}\Delta H &= \Delta P/pg\\&= \Delta PRT/Pg\\&= (100100-99600)^{*}287.058^{*}(5+273.15)/(100100^{*}9.81)\\&= 40.7m.\end{aligned}$$

Embodiments described herein update the reference demark pressure using a demark barometer mounted to the base station (e.g., communicatively coupled to the base station and kept at a relatively fixed altitude). For example, the demark barometer (e.g., other modules **136**) may be integrated with the base station or plugged into or electrically coupled to the base station. Reference demark pressures may be communicated to the UAV over one or more wired and/or wireless communication links established between the base station and the UAV, for example, and the UAV may be configured to determine a flight altitude estimate based on the reference demark pressures and flight pressures provided by a flight barometer (e.g., other modules **126** and/or **152**) mounted to the UAV.

In various embodiments, it is not necessary to keep the location of the demark barometer constant (e.g., the same as the take-off location of the UAV), because the flight altitude estimation can compensate for a demark location change using a demark excursion pressure adjustment defined as the pressure difference between a first demark pressure at the take-off location and a second demark pressure at a new location, where the change in location (e.g., the base station exclusion) takes place over a relatively short period of time (e.g., less than approximately 1 hour). The demark excursion pressure adjustment may be added to the subsequent series of reference demark pressures or subtracted from subsequent flight pressures, and then the flight altitude estimation may proceed as normal.

As ambient atmospheric pressure change is a relatively slow process, the update frequency of the reference demark pressure can be 1 Hz or lower. However, the validation of the measurement should be implemented as part of the flight control process, for example, so as to avoid sudden ascents/descents due to intermittently inaccurate, garbled, or wild readings or sensor failure. For example, assuming the reference demark pressure P**0** is 101325 Pa, if a subsequent demark pressure measurement is out of the range 96325 Pa to 106325 Pa (P**0**−5000 Pa to P**0**+5000 Pa, where 5000 Pa is a predetermined demark pressure dynamic range threshold), that subsequent demark pressure measurement is considered invalid and omitted from the flight altitude estimation. Such dynamic range threshold may be suspended or increased while the base station location is changed, such as by user input provided to the base station.

FIG. **6** illustrates a flow chart of a control loop to determine flight altitude estimates where the reference demark pressure is not assumed to be constant. In particular, block **602** of control loop **400** represents initiation of execution of control loop **600** (e.g., by controller **112** of UAV **110** and/or user interface **132** of base station **130** or OCU **332**), which may include initializing a fight barometer mounted to UAV **110** and/or a demark barometer mounted to base station **130/330**. Block **604** represents a delay of further execution of control loop **600** until UAV **110** receives or generates a flight initiation command (e.g., to take off at or near base station **130/330**). In block **606**, UAV **110** receives a ground or reference pressure measurement P**0** from the flight barometer coupled to UAV **110** after the flight initiation command is received or generated and before flight initiation commences, for example, and stores the ground or reference pressure measurement P**0**. At approximately the same time, base station **130/330** receives a ground or reference pressure measurement Pg**0** from a demark barometer mounted to base station base station **130/330** after the flight initiation command is received or generated and before flight initiation commences, for example, and stores the ground or reference pressure measurement Pg**0**. In various embodiments, such ground or reference pressure measurements may be stored locally at either UAV **110** and/or base station **130/330**, for example, and/or may be communicated to UAV **110** and/or base station **130/330** as telemetry data for remote storage, for example, and/or for display to an operator of system **100**. In block **608**, UAV **110** determines it has initiated flight, such as by evaluating telemetry from various sensors, for example, and proceeds to blocks **620** and **630**.

In block **620**, periodic flight pressure measurements P are made using the flight barometer based on various criteria, such as reaching a preset maximum time duration between flight pressure measurements, reaching a designated waypoint in a planned route, and/or during a relatively complex maneuver, where the flight pressure measurements may be made up to approximately the maximum rate supported by the flight barometer and/or various elements of system **100**. In block **630**, and substantially in parallel, with block **620**, periodic demark pressure measurements Pg are made using the demark barometer based on various criteria, such as reaching a preset maximum time duration between demark pressure measurements, for example, and/or during a relatively dynamic atmospheric pressure period, where the atmospheric pressures vary relatively rapidly and the demark pressure measurements may be made up to approximately the maximum rate supported by the demark barometer and/or various elements of system **100**. In some embodiments, such criteria for the demark pressure measurements may include receiving user input indicating a change in location of base station **130/330**, for example, where the user indicates the start and end of such change in location so that a demark excursion pressure adjustment may be determined and/or stored based on the differential demark pressures attributed to the location change, as described herein. In various embodiments, the timing criteria of periodic flight and demark pressure measurements may be substantially synchronized in time. In block **632**, measured demark pressures are checked against a demark pressure dynamic range threshold before such demark pressures are stored and/or used to determine a flight altitude estimation, as shown in block **610**.

In block **610**, a real-time pressure differential flight altitude estimation H is determined (e.g., by controller **112** and/or various elements of systems **100**/**300**) based on the stored ground or reference flight pressure measurement P**0**, the stored ground or reference demark pressure measurement Pg**0**, and the most recent flight pressure measurement P and demark pressure measurement Pg. In some embodiments, such differential flight altitude estimation H may be used for autopiloting UAV **110** and/or stored for later telemetry graphing or mapping, for example, and/or may be communicated to base station **130** as telemetry data for remote storage and/or display to an operator of system **100**. As discussed herein, such differential flight altitude estimation H is a substantially more reliable flight altitude estimation with respect to the actual altitude of UAV **110**, particularly when flown over relatively long periods of time (e.g., over 1 hour). In various embodiments, differential flight altitude estimation H may be determined from $H=(P0+(Pg-Pg0)-P)/pg$. In block **614**, UAV **110** determines whether it has completed a flight or landed, such as by evaluating telemetry from various sensors, for example, and either continues to iteratively execute blocks **620**-**632** (e.g., while still in flight or executing a planned route), or proceeds to block **614**, which represents ending execution of control loop **600**.

FIG. **7** illustrates a flow diagram **700** of various operations to provide flight altitude estimates using UASs **100** and/or **300** in accordance with an embodiment of the disclosure. In some embodiments, the operations of FIG. **7** may be implemented as software instructions executed by one or more logic devices or controllers associated with corresponding electronic devices, sensors, control loops, and/or structures depicted in FIGS. **1**-**6**. More generally, the operations of FIG. **7** may be implemented with any combination of software instructions, mechanical elements, and/or electronic hardware (e.g., inductors, capacitors, amplifiers, actuators, or other analog and/or digital components). It should also be appreciated that any step, sub-step, sub-process, or block of process **700** may be performed in an order or arrangement different from the embodiment illustrated by FIG. **7**. For example, in other embodiments, one or more blocks may be omitted from or added to the process. Furthermore, block inputs, block outputs, various sensor signals, sensor information, calibration parameters, and/or other operational parameters may be stored to one or more memories prior to moving to a following portion of a corresponding process. Although process **700** is described with reference to systems described in FIGS. **1**-**6**, process **700** may be performed by other systems different from those systems and including a different selection of electronic devices, sensors, assemblies, mechanisms, platforms, and/or platform attributes.

At block **702**, flight pressure data is received. For example, controller **112**, communication module **120**, user interface **132**, and/or communication module **132** may be configured to receive flight pressure data generated by a flight barometer mounted to UAV **110**. In various embodiments, such flight pressure data may be received as UAV **110** maneuvers within a survey area, either while tethered or under free flight conditions. At block **704**, demark pressure data is received. For example, controller **112**, communication module **120**, user interface **132**, and/or communication module **132** may be configured to receive demark pressure data generated by a demark barometer mounted to base station **130**. In various embodiments, such demark pressure data may be received as UAV **110** maneuvers within a survey area, for example, or as base station is moved between locations while remaining able to communicate with UAV **110**. In block **706**, a differential flight altitude estimation is determined. For example, controller **112**, communication module **120**, user interface **132**, and/or communication module **132** may be configured to determine the differential flight altitude estimation based, at least in part, on the received flight pressure data and demark pressure data, a reference flight pressure corresponding to a flight initiation location of the UAV, and a reference demark pressure corresponding to a flight initiation location of the base station, as described herein.

In various embodiments, a time series of such differential flight altitude estimations may be determined, such as corresponding to one or more positions of UAV **110** within a survey area, for example, and an elevation map may be generated and/or displayed to an operator of systems **100**/**300**, based on the time series of differential flight altitude estimations. In some embodiments, such differential flight altitude estimations may be used to autopilot UAV **110** according to a designated surveillance route and/or tether extent, for example.

By providing such systems and techniques for flight altitude estimation, embodiments of the present disclosure substantially improve the operational flexibility and reliability of unmanned sensor platforms. Moreover, such systems and techniques may be used to increase the operational safety of unmanned mobile sensor platforms above that achievable by conventional systems. As such, embodiments provide mobile sensor platforms systems with significantly increased survey convenience and performance.

Where applicable, various embodiments provided by the present disclosure can be implemented using hardware, software, or combinations of hardware and software. Also, where applicable, the various hardware components and/or software components set forth herein can be combined into composite components comprising software, hardware, and/or both without departing from the spirit of the present disclosure. Where applicable, the various hardware components and/or software components set forth herein can be separated into sub-components comprising software, hardware, or both without departing from the spirit of the present disclosure. In addition, where applicable, it is contemplated that software components can be implemented as hardware components, and vice-versa.

Software in accordance with the present disclosure, such as non-transitory instructions, program code, and/or data, can be stored on one or more non-transitory machine readable mediums. It is also contemplated that software identified herein can be implemented using one or more general purpose or specific purpose computers and/or computer systems, networked and/or otherwise. Where applicable, the ordering of various steps described herein can be changed, combined into composite steps, and/or separated into sub-steps to provide features described herein.

Embodiments described above illustrate but do not limit the invention. It should also be understood that numerous modifications and variations are possible in accordance with the principles of the present invention. Accordingly, the scope of the invention is defined only by the following claims.

The invention claimed is:

1. A system comprising:
a logic device configured to communicate with a communication module and a flight barometer coupled to an unmanned aerial vehicle (UAV), wherein the communication module is configured to establish a communication link with a base station associated with the UAV, the flight barometer is configured to provide flight pressures associated with the UAV as it maneuvers within a survey area, and the logic device is configured to:
receive flight pressure data from the flight barometer corresponding to one or more positions of the UAV within the survey area;
receive demark pressure data from a demark barometer coupled to the base station; and
determine a differential flight altitude estimation based, at least in part, on the received flight pressure data and demark pressure data, a reference flight pressure corresponding to a flight initiation location of the UAV, and a reference demark pressure corresponding to a flight initiation location of the base station.

2. The system of claim **1**, wherein the logic device is configured to:
determine a time series of differential flight altitude estimations based, at least in part, on the received flight pressure data and demark pressure data, the reference flight pressure corresponding to the flight initiation location of the UAV, and the reference demark pressure corresponding to the flight initiation location of the base station; and
generate an elevation map corresponding to the one or more positions of the UAV within the survey area, wherein the elevation map is based, at least in part, on the determined time series of differential flight altitude estimations.

3. The system of claim **1**, wherein the logic device is configured to:
autopilot the UAV according to a designated surveillance route based, at least in part, on the determined differential flight altitude estimation.

4. The system of claim **1**, wherein the logic device is configured to:
determine a demark excursion pressure adjustment based, at least in part, on first and second demark pressures associated with respective first and second locations of the base station; and
determine the differential flight altitude estimation based, at least in part, on the determined demark excursion pressure adjustment.

5. The system of claim **1**, wherein:
the logic device is coupled to the UAV; and
the reference demark pressure is received from the base station over the communication link and stored at the UAV.

6. The system of claim **1**, wherein:
the logic device is coupled to the base station; and
the reference flight pressure is received from the UAV over the communication link and stored at the base station.

7. The system of claim **1**, further comprising:
the UAV comprising the communication module and the flight barometer; and
wherein the communication link is via a tether coupled to the UAV.

8. The system of claim **7**, further comprising:
the base station; and
wherein the tether is coupled between the UAV and the base station.

9. The system of claim **8**, wherein:
the base station further comprises the demark barometer; and
the UAV comprises a fixed wing or a copter type of aircraft.

10. A method of using the system of claim **1**, the method comprising:
receiving the flight pressure data from the flight barometer coupled to the UAV, wherein the flight barometer provides flight pressures associated with the UAV as it maneuvers within the survey area and the flight pressure data corresponds to one or more positions of the UAV within the survey area;
receiving the demark pressure data from the demark barometer coupled to the base station; and
determining the differential flight altitude estimation based, at least in part, on the received flight pressure data and the demark pressure data, the reference flight pressure corresponding to the flight initiation location of the UAV, and the reference demark pressure corresponding to the flight initiation location of the base station.

11. A method comprising:
receiving flight pressure data from a flight barometer coupled to an unmanned aerial vehicle (UAV), wherein the flight barometer is configured to provide flight pressures associated with the UAV as it maneuvers within a survey area and the flight pressure data corresponds to one or more positions of the UAV within the survey area;
receiving demark pressure data from a demark barometer coupled to a base station; and
determining a differential flight altitude estimation based, at least in part, on the received flight pressure data and demark pressure data, a reference flight pressure corresponding to a flight initiation location of the UAV, and a reference demark pressure corresponding to a flight initiation location of the base station.

12. The method of claim **11**, further comprising:
determining a time series of differential flight altitude estimations based, at least in part, on the received flight pressure data and demark pressure data, the reference flight pressure corresponding to the flight initiation location of the UAV, and a reference demark pressure corresponding to the flight initiation location of the base station; and
generating an elevation map corresponding to the one or more positions of the UAV within the survey area, wherein the elevation map is based, at least in part, on the determined time series of differential flight altitude estimations.

13. The method of claim **11**, further comprising:
autopiloting the UAV according to a designated surveillance route based, at least in part, on the determined differential flight altitude estimation.

14. The method of claim **11**, further comprising:
determining a demark excursion pressure adjustment based, at least in part, on first and second demark pressures associated with respective first and second locations of the base station; and

determining the differential flight altitude estimation based, at least in part, on the determined demark excursion pressure adjustment.

15. The method of claim **11**, wherein:

the reference demark pressure is received from the base station over a communication link and stored at the UAV.

16. The method of claim **11**, wherein:

the reference flight pressure is received from the UAV over a communication link and stored at the base station.

17. The method of claim **11**, wherein communication between the base station and the UAV is via a tether coupled between the UAV and the base station.

18. A system for performing the method of claim **11**, the system comprising:

a logic device configured to perform the determining of the differential flight altitude estimation;

the base station; and

the UAV comprising the flight barometer.

19. The system of claim **18**, wherein:

the base station comprises the demark barometer; and

the UAV comprises a fixed wing or a copter type of aircraft.

20. The system of claim **18**, further comprising:

a tether coupled between the UAV and the base station and configured to provide power to the UAV and form a communication link between the UAV and the base station.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 11,417,223 B2
APPLICATION NO. : 17/148495
DATED : August 16, 2022
INVENTOR(S) : Michael Tribou et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

In Column 20, Line 51, Claim 12, change “and a reference” to --and the reference--.

Signed and Sealed this
First Day of August, 2023

Katherine Kelly Vidal

Katherine Kelly Vidal
Director of the United States Patent and Trademark Office